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Research on Structural Lay-up Optimum Design of Composite Wind Turbine Blade

Zhang Lanting*

College of Mechanical Engineering, Inner Mongolia University of Technology, Hohhot, Inner Mongolia, 010051, China

Abstract

According to theoretical calculating result of stress, four different lay-up structures of 1.2MW horizontal axis wind turbine blade, which can effectively endure various loads, are designed primarily. Based on composite laminate theory and finite element method, through analyzing their stress-strain, the optimal lay-up schema is confirmed. The verified analysis of stiffness and strength were performed under extreme load conditions. Numerical analysis results show that the designed blade structure was safe, and the value of stress and strain was low.

Keywords: lay-up optimum design; structural analysis; wind turbine blade; composite

1. Introduction

As the renewable, green and environmental protection energy, wind energy resource is one of the most developing hi-technologies in energy field. The blades of wind turbine rotor are regarded as the most critical component of the wind turbine system. Because of its special functions, such as high specific stiffness and specific strength, better designability, high performance of antifatigue and antifailure, easy integral molding of large-area and wonderful corrosion resistance, reinforced composite material is widely applied in large scale wind turbine blades. With the development to large power, light weight and high performance ratio, large scale wind turbine blades is basically made of reinforced material and thermosetting base-resin, and produced through lay-up process at present[1,2].

Motion and stress status of wind turbine blade is very complicated. In order to improve its performance, quality and fatigue life, it is necessary to design different lay-up structures according to calculating results and experience in blade design stage. Through stress-strain analysis of different

* Corresponding author: Zhang Lanting. Tel.: +86-471-6575464; fax: +86-471-6577339
E-mail address: zhlt1234@126.com

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structures, the optimal lay-up schema can be determined, and the verified analysis of stiffness and strength can be performed under extreme load conditions.

2. 1.2 MW Wind turbine blade

Design power of wind generating set is 1.2MW, rated rotational speed is 20 rpm, rated wind speed is 13m/s, maximum tip ratio of transmission is 7.6, blade number is 3, and blade length is 30m. NACA 64-618 airfoil was used at the blade tip to keep good aerodynamic performance, and DU and EU airfoil were used at the blade root for good structural performance. The profile of 1.2 MW wind turbine blade was designed based on BEM theory and modified Wilson algorithm. Through correcting the airfoil from structure and processing point, the relative thickness distribution of the blade wing and the solid model of the blade are individually shown as in Fig.1 and Fig.2.

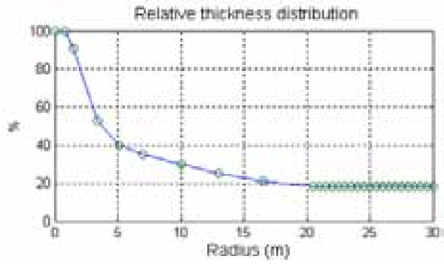

Fig.1 Relative thickness distribution of wing

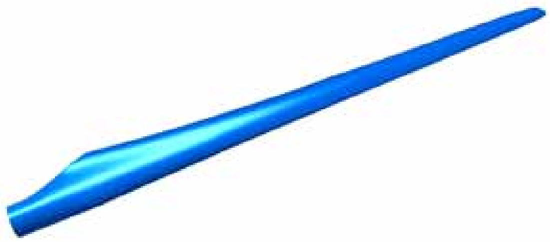

Fig.2 The blade solid model of windward side

3. Primary design of blade lay-up structures

Blade mainly endures tension and compression stress, bending stress and distorting stress produced by aerodynamical, centrifugal and gravitational loads in its operating process. The skin-spar-foam sandwich structure was used to minimize the blade weight and to get the structural stability against buckling and vibration. The blade can be regarded approximately as one-way bearing component. Because the maximum stress generates on blade root, and stress gradually reduces along blade length, the maximum lay-up thickness should locate in the blade root[3-4]. Table 1 presents the designed laminate thickness of blade. The thickness of blade root is 80 mm, and the thickness of blade tip is 20 mm. From root to tip, the thickness of blade sequentially reduces.

Table 1 Blade design thickness of different cross-sections

Order number of cross-section	1	2	3	4	5	6	7
Position of cross-section[m]	0	0.85	5.1	7.5	10	12.5	13
Thickness of laminate [mm]	80	75	70	65	60	60	55
Order number of cross-section	8	9	10	11	12	13	14
Position of cross-section [m]	15.0	17.5	20	22.5	25	27.5	30
Thickness of laminate [mm]	50	45	40	35	30	25	20

According to curved face form, performance requirement, magnitude and direction of load under working condition, composite lay-up design of wind turbine blade mainly determines lay-up angle, lay-up thickness and lay-up sequence. Design must be satisfied the main technological demands of resisting ultimate loads, deflection in the permissible range and avoiding resonance[5-6].

Based on composite laminate theory, design structures of different laminates can be determined primarily according to loading characteristic and stress relationship of composite blade. Through calculating stress relationship of different cross-sections, the main ratio between positive stress and shear stress have 5:1, 7:1 and 9:1. When the ratio is 7:1 and 9:1, action of shear stress is little. Placing 0° and 90° fiber resists bending, and placing 15° and 30° fiber resists shearing and bending in Y direction. When the ratio is 5:1, placing 0° and 90° fiber resists bending, and 45° fiber resists shearing. Therefore, four different kinds of fiber lay-up schemes are obtained. They are $[0°/\pm15°/90°]_S$, $[0°/\pm30°/90°]_S$, $[0°/\pm45°/90°]_S$ and $[0°/\pm60°/90°]_S$.

4. Structural analysis of different lay-ups

Static numerical simulation of wind turbine blade is to analyze and study its stress and strain of different lay-up structures. and then to determine the optimal lay-up schema aimed the maximum structure strength and stiffness as final goal.

To finite element analysis of composite lay-up structure, different laminations adopt different element types and attributes. Because of the random orthogonal aeolotropism of GRP mechanical performance, material performance relates to its main arbor orientation, lay-up number and lay-up thickness. Special layer elements is used to simulate composite, and composite parameters of the blade, such as lay-up angle, lay-up number and lay-up thickness can be set. The boundary condition of finite model is to fix the blade root fully, to act wind pressure on the blade out-surface, and to act weight and centrifugal loads on calculating model. When blade is rotating, its stress changes with rotating position. The extreme stress is calculated in the extreme wind speed 60 m/s and 0° dangerous position which bears the maximum stress. Figs.3-6 show the Von Mises equivalent stress analysis results of four lay-up structures.

Table 2 presents the Von Mises equivalent stress analysis results of four lay-up cases under extreme loads.

Table 2 Von Mises equivalent stress analysis results

No.	lay-up sequence	Von Mises equivalent stress [Pa]
1	$[0/\pm15/90]_S$	4.26E+06
2	$[0/\pm30/90]_S$	4.06E+06
3	$[0/\pm45/90]_S$	3.91E+06
4	$[0/\pm60/90]_S$	3.85E+06

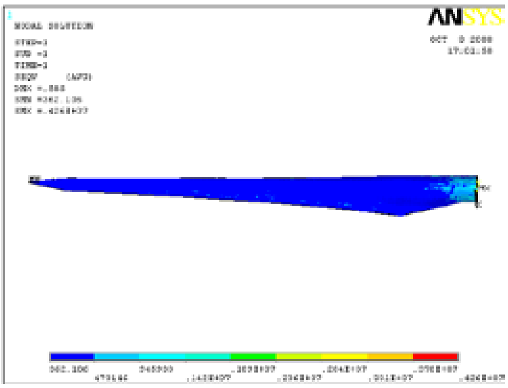

Fig.3 Von Mises equivalent stress of $[0/\pm15/90]_S$

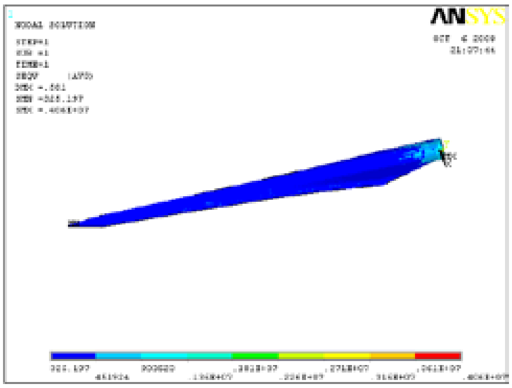

Fig.4 Von Mises equivalent stress of $[0/\pm30/90]_S$

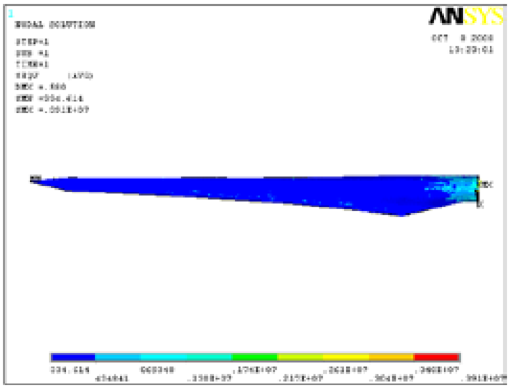

Fig.5 Von Mises equivalent stress of $[0/\pm45/90]_S$

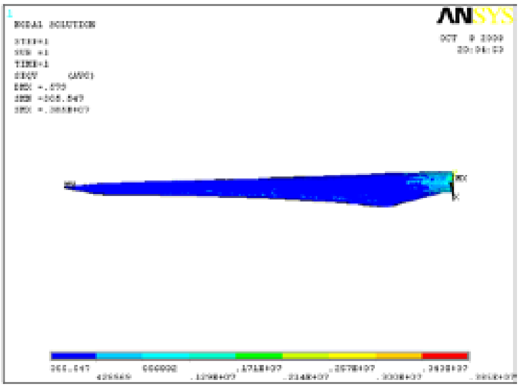

Fig.6 Von Mises equivalent stress of $[0/\pm30/90]_S$

According to the results of this analysis, the maximum equivalent stress is generated on blade root under extreme loads, and it is caused by centrifugal load. The maximum equivalent stress occurs in $[0°/\pm15°/90°]_S$, and the minimal one occurs in $[0°/\pm60°/90°]_S$.

Figs.7-10 shows the total deformation of four lay-up structures.

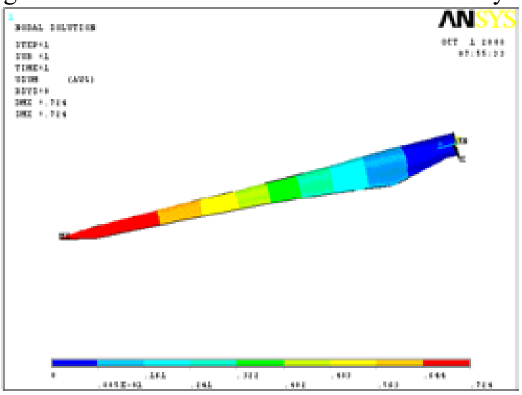

Fig.7 Total deformation of $[0/\pm15/90]_S$

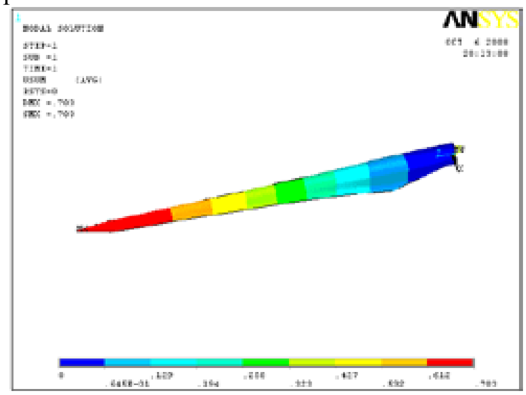

Fig.8 Total deformation of $[0/\pm30/90]_S$

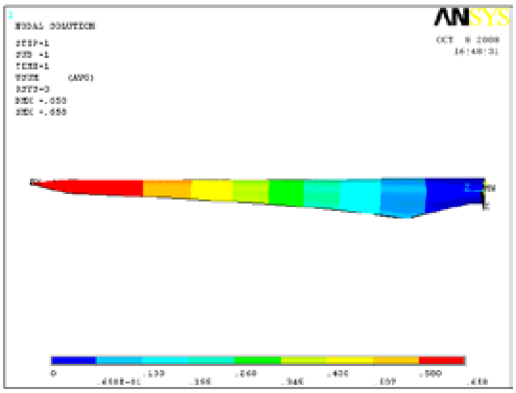

Fig.9 Total deformation of $[0/ \pm45/90]_S$

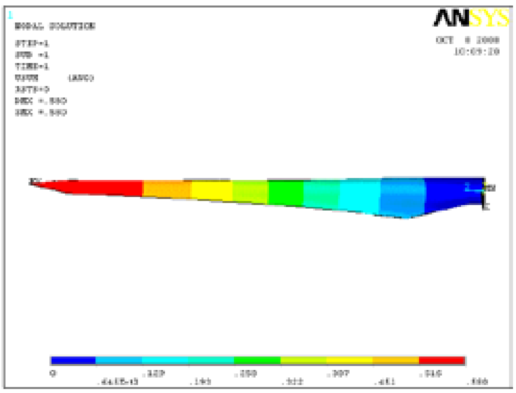

Fig.10 Total deformation of $[0/\pm60/90]_S$

Table 3 presents the maximum placement and tip deflection results under extreme loads.

Table 3 Displacement and deflection for different lay-ups

No.	lay-up sequence	Displacement of blade tip[m]	Deflection of blade tip
1	$[0/\pm15/90]_S$	0.724	2.41%
2	$[0/\pm30/90]_S$	0.703	2.34%
3	$[0/\pm45/90]_S$	0.658	2.19%
4	$[0/\pm60/90]_S$	0.580	1.94%

According to the results of this analysis, the maximum placement of blade is generated on the blade tip, and it is caused by wind pressure. The maximum placement occurs in $[0°/\pm15°/90°]_S$, and the minimal one occurs in $[0°/\pm60°/90°]_S$.

5. Determining the optimal lay-up design and verifying its strength and stiffness

Through comparing the Von Mises stress and tip placement of four lay-up schemes, the $[0°/\pm60°/90°]_S$ is the optimal lay-up structure. Table 4 present the placement analysis results of some cross-sections.

Table 4 Displacement of different cross-sections

Position of cross-section (m)	5	10	15	20	25	30
Displacement (m)	0.085	0.195	0.327	0.436	0.514	0.580

The curve of placement distribution is approximately linear. The maximum placement is 0.580 m, and on the tip part. The maximum deflection is 1.93 percent of the whole blade length, and it satisfied the design stiffness demand.

Strength of composite materials relates to its performance and stress-strain status and strain energy after loading. At present, macromechanics strength theory and micromechanics strength theory are the main strength theory of composite materials. Strength theory of macromechanics has developed relative mature stage. Maximum stress criterion and maximum strain criterion based on macroscopic damage criterion are the best macroscopic strength theory to analyze strength problem of composite materials[7-8]. Because of its high precision and wide application, the maximum stress criterion is adopted in this study. It demands that every stress must be less than their ultimate strength. Otherwise the blade will be failure.

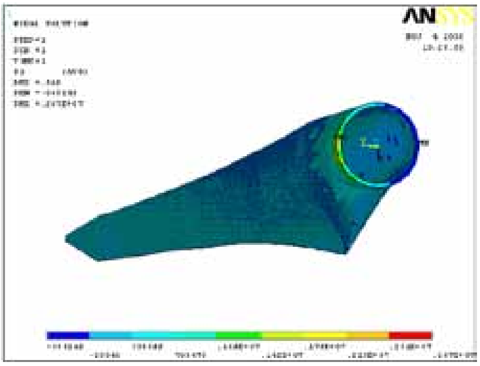

Fig.11 First principle stress of the blade

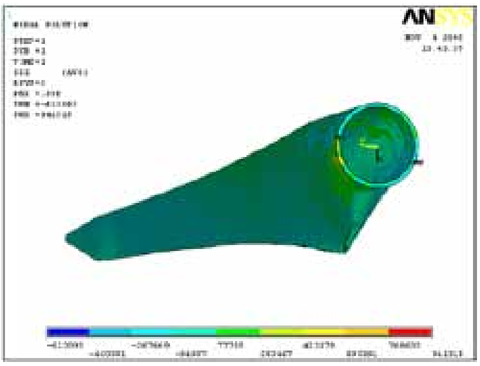

Fig 12 XY shear stress of the blade

Strength analysis under extreme loads is shown as in Fig.11 and Fig.12. According to the results of this analysis, the maximum first principal stress occurs on the blade root, and it is 2.87 MPa. Allowable stress was 28.99MPa. The maximum shearing stress occurs on the blade root too, and it is 0.941 MPa. Allowable shearing stress was 11.63 MPa. Since the safety factor for the allowable stresses was 5.0, which was calculated from the allowable stress and the predicted stress, the designed wind turbine blade satisfied the design strength demand.

6. Conclusion

Lay-up design and verified analysis of stiffness and strength are the very important work in the design of large scale composite wind turbine blade. An E-glass/epoxy composite blade for a 1.2MW HAWTS was designed and analyzed in this paper. According to stress calculating results and experience, four different kinds of fiber lay-up schemes are designed. Aimed the maximum structure strength and stiffness as final goal, through stress-strain analysis of different structures, the optimal lay-up schema $[0°/\pm60°/90°]_S$ was determined. The verified analysis of stiffness and strength of the optimal lay-up schema is performed under extreme load conditions. Numerical calculation shows that the curve of placement distribution is approximately linear, and the maximum deflection of the blade tip satisfied the design stiffness demand. The maximum stress criterion is adopted, and the maximum first principal stress and shearing stress of the blade root both satisfy the design strength demand.

Acknowledgements

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References

[1] Shirinzadeh B, Alici G, Foong C W, et al. Fabrication process of open surfaces by robotic fibre placement. *Robotics and Computer-Integrated Manufacturing* 2004, 20

[2] Chen Shao-jie, Composites and Wind Turbine Blades. *Hi-Tech Fiber&Application.* 2007;**32**: 8-12

[3] Serek Berry and Steve Lockard. Parametric Study for Large Wind Turbine Blades. *SAND 2002-2519,* Unlimited Release Printed; 2002

[4] C. Kong, J. Bang, Y. Sugiyama. Structural Investigation of Composite Wind Turbine Blade Considering Various Load Cases and Fatigue Life. *Energy* 2005;**30**:2101-2114

[5] Bao Hongbo. Stress and Model Analysis of Compound Blade Under Wind Pressure and Centrifugal Load. *Power System Engineering* 2007;**23**: 68-69

[6] Qi Qige. Study on the Structure and Placement of the Wind Turbine Blade. Inner Mongolia University of Ttechnology. 2008

[7] Wang Baolai, Wu Shiping, Liang Jun. Strength Theory and Failure Analysis of Composite Materials. *Failure Analysis and Prevention*. 2006;*2*:13-19

[8] Huang Zhengming, Zhang Huashan. Current Status and Future Trend of Researches on the Strength of Fiber-Reinforced Composites--A Summary of The Results From a “Failure Olympics” . *Advances in Mechanics*. 2007;**35**:80-98